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Jawaharlal Nehru
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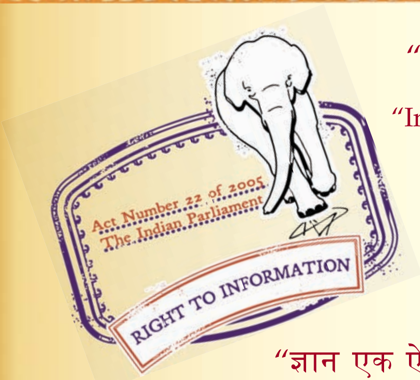
IS 11645 (1985): Test procedures for amplifiers and preamplifiers for semiconductor detectors for ionizing radiation [LITD 8: Electronic Measuring Instruments, Systems and Accessories]

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Bhartṛhari—Nītiśatakam
"Knowledge is such a treasure which cannot be stolen"

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IS : 11645-1985
IEC Pub 340 (1979)
( Reaffirmed 2001 )

*Indian Standard*

# TEST PROCEDURES FOR AMPLIFIERS AND PREAMPLIFIERS FOR SEMICONDUCTOR DETECTORS FOR IONIZING RADIATION

UDC 621·375 : 539·1074·55 : 539·12·08:620·1



BUREAU OF INDIAN STANDARDS
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Gr 12 *November* 1987

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# TEST PROCEDURES FOR AMPLIFIERS AND PREAMPLIFIERS FOR SEMICONDUCTOR DETECTORS FOR IONIZING RADIATION

**National Foreword**

This Indian Standard, which is identical with IEC Pub 340 (1979) 'Test procedures for amplifiers and preamplifiers for semiconductor detectors for ionizing radiation' issued by the International Electrotechnical Commission (IEC), was adopted by the Indian Standards Institution on the recommendation of the Nuclear Instrumentation Sectional Committee and approval of the Electronics and Telecommunication Division Council.

Wherever the words 'International Standard' appear, referring to this standard, they should be read as 'Indian Standard'.

**Cross References**

In this Indian Standard, the following International Standards are referred to. Read in their respective places the following:

| *International Standard* | *Corresponding Indian Standard* |
|---|---|
| IEC Pub 50 (391) 1975 Detection and measurement of ionizing radiation by electric means | IS : 1885 (Part 63)-1985 Electrotechnical vocabulary: Part 63 Nuclear Instrumentation |
| IEC Pub 333 (1983) Test procedures for semiconductor charged—particle detectors | IS : 11425-1985 Test procedures for semiconductor charged—particle detectors |

The technical committee responsible for the preparation of this Indian Standard has reviewed the provisions of the following IEC standard and has decided that it is acceptable for use in conjunction with this standard.

IEC Pub 430 (1973) Test procedures for germanium gamma-ray detectors

Only the English language text of the International Standard has been retained while adopting it in this Indian Standard.

Nuclear Instrumentation Sectional Committee, LTDC 26 [Ref : Doc : LTDC 26 (934)]

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## 1. Scope

These test procedures apply to amplifiers and preamplifiers for semiconductor detectors for ionizing radiation. Test procedures for associated detectors are described in IEC Publication 333, Test Procedures for Semiconductor Detectors for Ionizing Radiation, and IEC Publication 430, Test Procedures for Germanium Gamma-ray Detectors. This publication supersedes IEC Publications 340, First Edition (1970) and 340A (1974).

## 2. Object

To lay down standard test procedures for amplifiers and preamplifiers used with semiconductor detectors.

Semiconductor detectors have come into widespread use in recent years in the detection and high resolution spectroscopy of ionizing radiation. Silicon detectors have found their principal application in the detection and analysis of heavy charged particles, X-ray quanta and low energy gamma rays. Large volume detectors made of germanium have proved very useful in the detection and analysis of gamma radiation. The rapid development of these detectors has stimulated the development of electronic amplifiers and preamplifiers with characteristics that permit exploitation of the capabilities of the detectors. This has made desirable the establishment of standard test procedures so that measurements may have the same significance to all manufacturers and users.

This standard is not intended to imply that all tests described herein are mandatory; but only that such tests as are carried out on completed devices shall be performed in accordance with the procedures given herein.

# SECTION ONE — GENERAL REQUIREMENTS

## 3. Specification criteria

The electronics for semiconductor radiation detectors should be selected to complement some or all of the following useful characteristics of these detectors: good resolution, fast pulse rise time, excellent energy linearity, and low inherent noise. The performance of any component of an electronic system can be described in terms of its deviation from ideal behaviour. Since the detector user seeks pulse height and timing information, it is reasonable to specify amplifier performance in terms of pulse height spectral distortion and timing distortion: It is essential that line and RF interference and ground loop noise do not influence the measurements substantially. Also, ripple, hum, etc., resulting from the detector bias supply, preamplifier and amplifier power supplies and other sources shall not significantly influence the parameter measurements.

## 4. Simulating the charge pulse of a detector

The output of a semiconductor detector is a quantity of charge. This charge amounts to a current pulse lasting from $\simeq 10^{-9}$ to $\simeq 10^{-6}$ s, depending upon detector geometry, bias voltage, type and orientation of ionizing event, etc. This charge pulse can be simulated by applying a voltage step to a small capacitor connected in series with the preamplifier input. A suitable voltage step can be produced by a mercury wetted contact relay type of pulse generator or a generator with equivalent characteristics. The circuit diagram of a typical "tail pulse" generator and its output pulse waveform are shown in Figures 1 and 2.

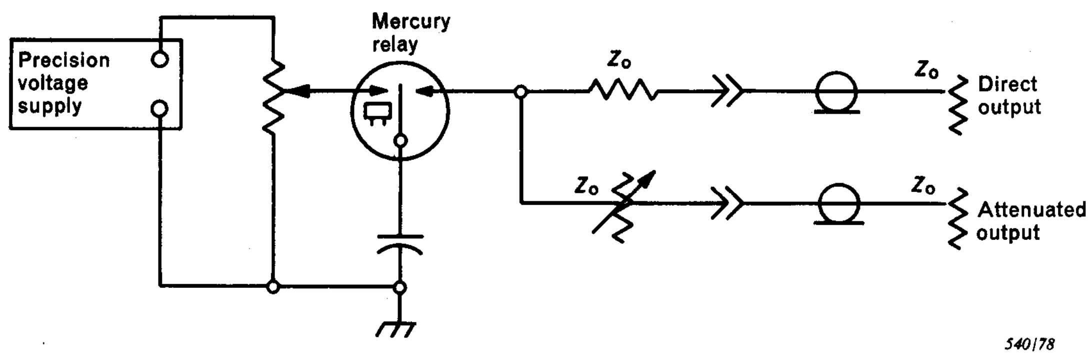



FIG. 1. — Precision pulse generator.

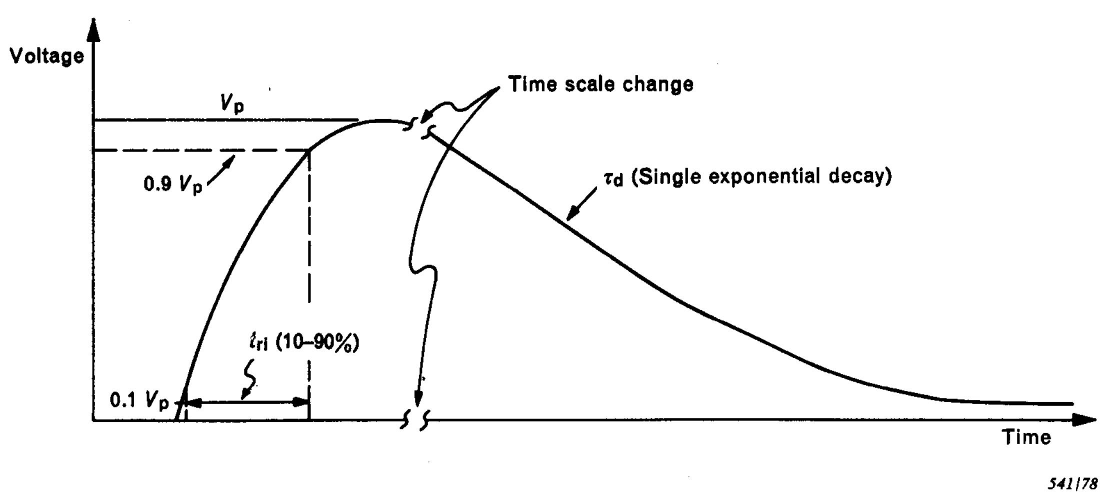



FIG. 2. — Precision pulse generator waveform.

A charge pulse generated by this waveform has two shortcomings:

1) it does not simulate the charge collection effects in the detector, and
2) the charge that is injected into the preamplifier during the rise time of the pulse is then removed during the fall time of the pulse. The removal of this charge causes an undershoot (baseline distortion) after each pulse.

In a circuit as shown in Figure 3, page 13, the maximum charge $Q$ delivered to the preamplifier is:

$$Q = C_c V_p \frac{1}{1 + C_c/A_0 C_f}$$

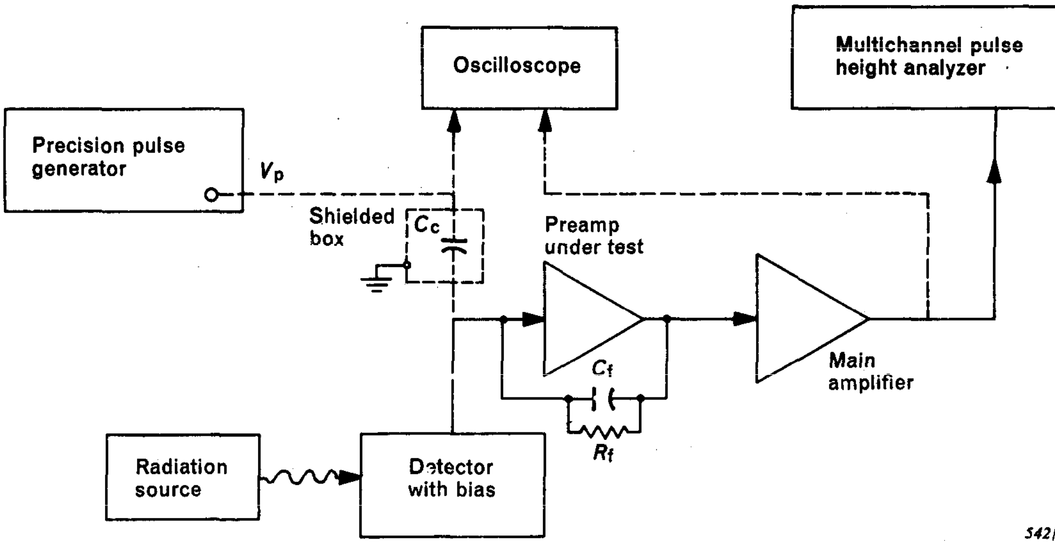



FIG. 3. — Measurement of pulse height distribution linewidth.

where:

$C_c$ is the value of the series capacitor

$V_p$ is the amplitude of the voltage step from the precision pulser

$A_0$ is the preamplifier open loop gain

$C_f$ is feedback capacitor for charge sensitive preamplifier

If $A_0 C_f \gg C_c$, then $$Q \simeq C_c V_p.$$

The pulse generator output as shown in Figure 2, page 11, decays witn a time constant $\tau_d$. In most cases, preamplifier response will be of the same type with a time constant $\tau_f = R_f C_f$. This means that the preamplifier response to the pulse generator will not be a simple exponential and, consequently, it will be impracticable to perform pole-zero cancellation in the main amplifier (see Clause 10). Consequently, when a tail pulse generator is used to simulate a charge input in parallel with an input from a detector, the spectrum from the detector will be distorted because of the undershoot produced by the tail pulse generator. This distortion will become more noticeable as the counting rate is increased. If the tail pulse generator is periodic, then the spectrum corresponding to the pulse generator output will not be distorted due to undershoot as the counting rate from the detector is varied.

## 5. Preamplifier conversion gain

The conversion gain $A_c$ of a charge sensitive preamplifier (or charge integrator) is defined by its output pulse amplitude, expressed in volts, divided by its input charge, expressed in coulombs. The conversion gain can also be expressed in volts per kiloelectron volt for a given detector material. In principle, the charge sensitive preamplifier consists of a high-gain wide-band voltage amplifier with a capacitive negative feedback $C_f$ as depicted in Figure 4.

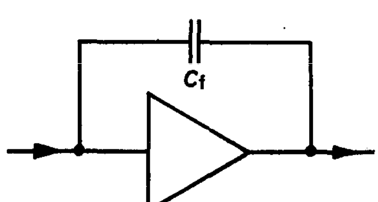



FIG. 4. — Circuit diagram of a charge sensitive preamplifier.

To measure the preamplifier conversion gain $A_c$, a precision pulse generator is used to apply a voltage step to a small and accurately known capacitor of the three-terminal type,* thereby injecting a charge pulse into the preamplifier input by the method described in Clause 4. The preamplifier output pulse $V_a$ is measured with an oscilloscope.

The conversion gain is:

$$A_c = \frac{V_a}{Q} = \frac{V_a}{C_c \cdot V_p}$$

where:

$C_c$ = capacitance, in farads, of charge injection capacitor
$Q$ = charge, in coulombs, into the preamplifier input
$V_a$ = preamplifier output voltage, in volts
$V_p$ = pulse generator output pulse amplitude, in volts

## 6. Preamplifier output pulse decay time constant

The preamplifier output pulse decay time constant can be measured by the circuit arrangement depicted in Figure 5.

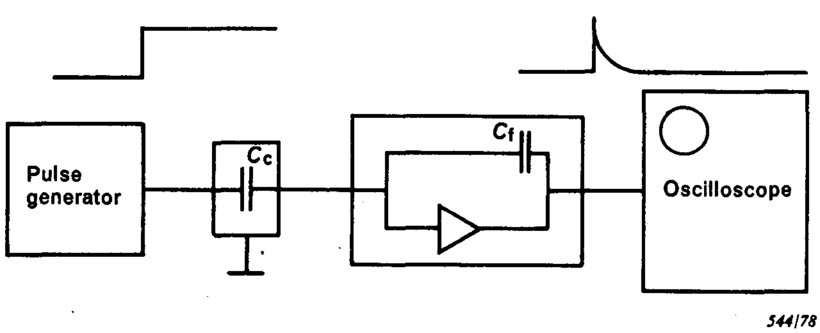



FIG. 5. — Circuit arrangement to measure preamplifier output pulse decay time constant.

The pulse generator must deliver a square wave pulse with negligible drop, and pulse length long with respect to the preamplifier decay time constant to be measured. The preamplifier decay time constant, i.e. time interval for the trailing edge of the output pulse amplitude to decrease from 100% to 100%/$e$, where $e = 2.72$, can be read from the oscilloscope. Some preamplifiers have a built-in differentiating network. To eliminate an undesirable undershoot, having a time constant equal to the decay time constant of the charge sensitive section of the preamplifier, a compensation network (pole-zero cancellation network) is usually included in the preamplifier. The pole-zero cancellation network should first be properly adjusted for minimum undershoot before preamplifier output pulse decay time constant is measured. The manufacturer shall state the decay time constant of the preamplifier, and the conditions under which it was measured.

* In the three-terminal type capacitor $C_0$ the capacitance is measured between two insulated terminals and the third terminal (connected to an electrostatic shield surrounding the capacitor) is grounded.

## 7. Measurement of main amplifier gain

The main amplifier gain should be measured by driving its input with a step function of known amplitude and measuring its output pulse amplitude with an oscilloscope. The main amplifier gain is numerically equal to the output pulse amplitude divided by the input pulse amplitude. The specified main amplifier gain should be for equal settings of the integrating and differentiating time constants. Furthermore, the gain for both unipolar and bipolar outputs should be the same. Any exception to either of these conditions shall be stated.

## 8. Specifying amplifier noise

The noise performance of an amplifier may be given unambiguously in units of voltage for a resistive signal source and in units of charge or energy for a capacitive signal source.

The output noise $e_{no}$ of an amplifier of gain $A$ can be expressed as an equivalent noise voltage $e_{ni}$, referred to the input, by:

$$e_{ni} = \frac{e_{no}}{A}$$

Noise can be expressed as a root-mean-square (r.m.s.) value $e_n$ as measured with a true r.m.s. meter, or as $\Delta$, the full width at half maximum (FWHM), as measured from a pulse amplitude distribution. The relation between the two measures, for noise having a Gaussian distribution, is

$$\Delta = 2\,(2 \log_e 2)^{1/2}\, e_n = 2.355\, e_n$$

The noise can be expressed in units of energy or charge by expressions given in Clause 15. Care must be taken that for all measurements of resolution the output pulse amplitude is within the linear region of the amplifier. Except in the case where an amplifier cuts off or distorts any portion of the noise, the measurement of noise with a true r.m.s. voltmeter is equivalent to noise measurement with a multichannel analyzer, within the respective accuracy of the two instruments (see Clause 15). Two examples where an r.m.s. noise meter will not give a true indication are the use of a biased amplifier (see Clause 23) and of a baseline restorer (see Clause 10). When measuring noise from a biased amplifier or a main amplifier with a baseline restorer (BLR), the multichannel analyzer method must be used.

## 9. Specifying amplifier nonlinearity

Amplifier nonlinearity results in distortion of pulse height spectra. Nonlinearity may be measured as integral nonlinearity (INL) and as differential nonlinearity (DNL). The integral nonlinearity is the departure from linear response expressed as a percentage of the maximum rated output pulse amplitude. The differential nonlinearity is the percentage deviation in incremental amplification of the amplifier referred to some standard points (see Clauses 21 and 22).

## 10. Specifying main amplifier shaping

Amplifiers for semiconductor radiation detectors may use different signal shaping methods. Usually they employ "quasi-gaussian" shaping and can be represented by the block diagram of Figure 6, page 19. Here the single differentiator and $n$ integrators perform the filtering of the input signal and noise. The pole-zero cancellation network transforms the preamplifier output signal into

the shape required to minimize undershoot after the differentiation. The range of preamplifier decay time constants that can be accommodated by the pole-zero network must be specified by giving the maximum and minimum input decay time constants.

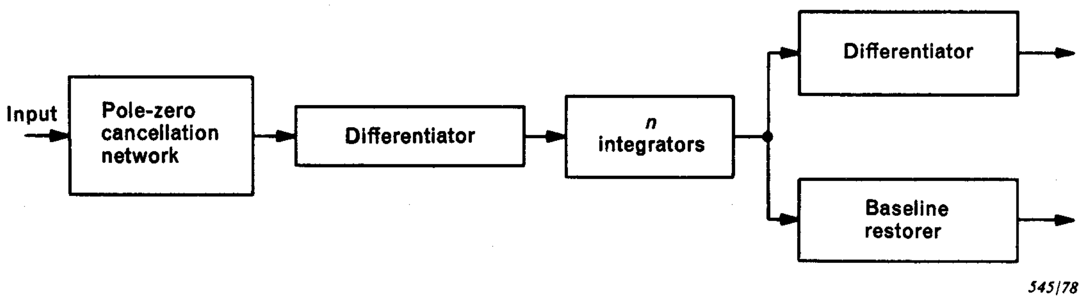



FIG. 6. — Schematic representation of the main amplifier shaping.

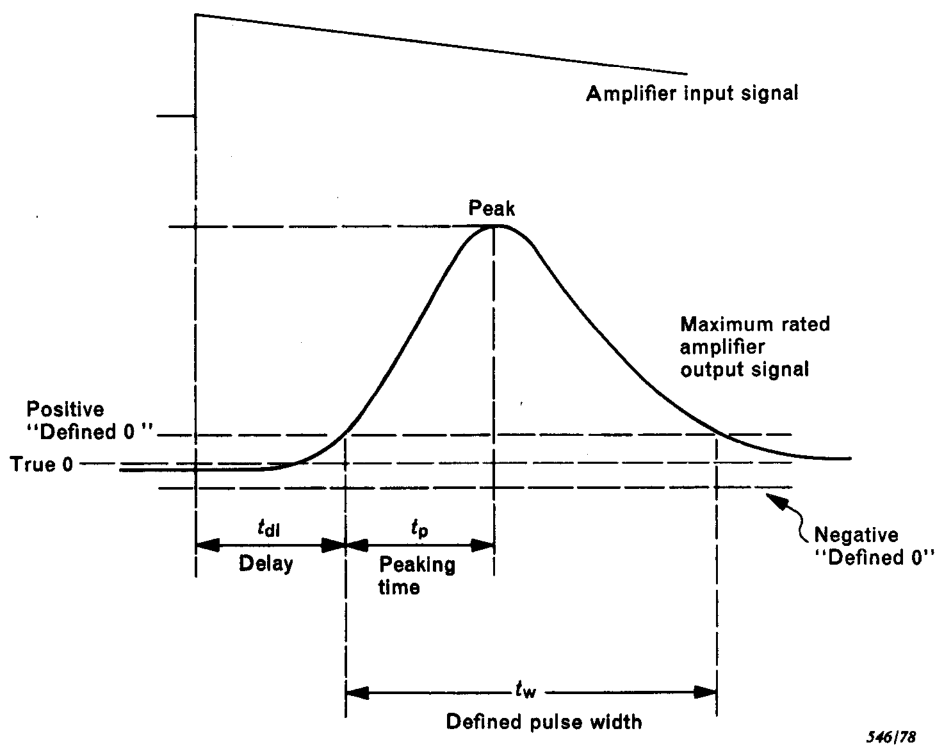



FIG. 7. — Output signal parameters.

The amplifier output signal parameters as defined in Figure 7 and described in this clause must be stated. "Defined zero" is an arbitrarily chosen voltage level at the amplifier output that is resolved from zero by the measuring apparatus and it depends on the precision and requirements of the measurement. It is recommended that it be 1/100 or 1/1 000 of the maximum linear peak amplitude.* The symbol $t_w$ represents the time the pulse exceeds its defined zero and may be specified at 0.1% and/or 1% of the maximum pulse amplitude. The circuit in Figure 8, page 21, is recommended for measuring $t_w$.

* Normally a 1/100 defined zero level will be used for specifying X-ray amplifiers, and a 1/1 000 for amplifiers to be used with high resolution gamma-ray systems and other high resolution systems.

Adjust the pulser and amplifier gain to obtain the maximum rated output voltage from the amplifier. Adjust the oscilloscope sensitivity so that 1% or 0.1% of the maximum rated output voltage is easily identifiable. The overload effect on the oscilloscope can be reduced by using an overload limiter. The overload limiter may consist, for example, of low-capacitance high-frequency semiconductor diodes (such as Schottky barrier diodes) connected as shown in Figure 8. Peaking time $t_p$ is the time interval between the pulse crossing the defined zero and its departure from maximum amplitude. Delay time $t_{dl}$ is the time interval between arrival of the input pulse to the amplifier and the first crossing of the defined zero level at the output of the amplifier.

*Note.* — If the amplifier includes pulse distorting processing functions (such as stretchers, baseline restorers and biased amplifiers) these parameters must be specified at the output of the main filter network.

When specifying main amplifier shaping, maximum outpeak amplitude, defined zero, $t_{dl}$, $t_p$ and $t_w$ must be specified. If the second differentiator is used, $t_w$ extends to the second crossing of the defined zero level by the negative lobe of the pulse.

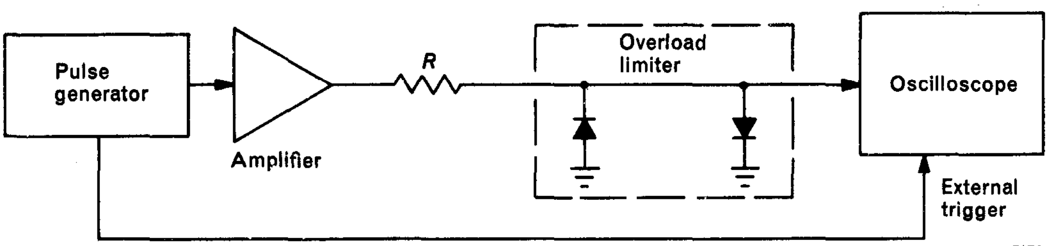



FIG. 8. — Circuit for measuring $t_w$.

There are other pulse shape specification methods in common use for which a single parameter characterizes the shaping. These methods use as a signal parameter the time constant $\tau$ = RC of an equivalent "semi-gaussian" filter, CR-(RC)$^n$, where $n$ is the number of integrating RC stages. Because of their ambiguity, these methods are not recommended. Their use is acceptable, however, if the relationship between $\tau$ and $t_p$, $t_{dl}$, and $t_w$ is clearly stated.

Baseline restoration is almost universally used to stabilize the baseline at the output of the amplifier. It influences amplifier resolution and counting rate performance, and sometimes linearity and stability. Usually only a few settings of the baseline restorer are provided. When specifying the amplifier, the BLR setting must be specified or it must represent the worst case.

## 11. Peak centre (centroid)

Calculate, point by point, the number of counts per channel less background ($N_x$ — $B_x$) as a function of channel number $X$. Determine the peak location $\hat{x}$ in terms of channel (and fractional channel) number. A convenient technique is the weighted average method of values of $N_x$ in the symmetrical portion of the peak, e.g. above the half maximum height:

$$\hat{x} = \frac{\Sigma X (N_x - B_x)}{\Sigma (N_x - B_x)}$$

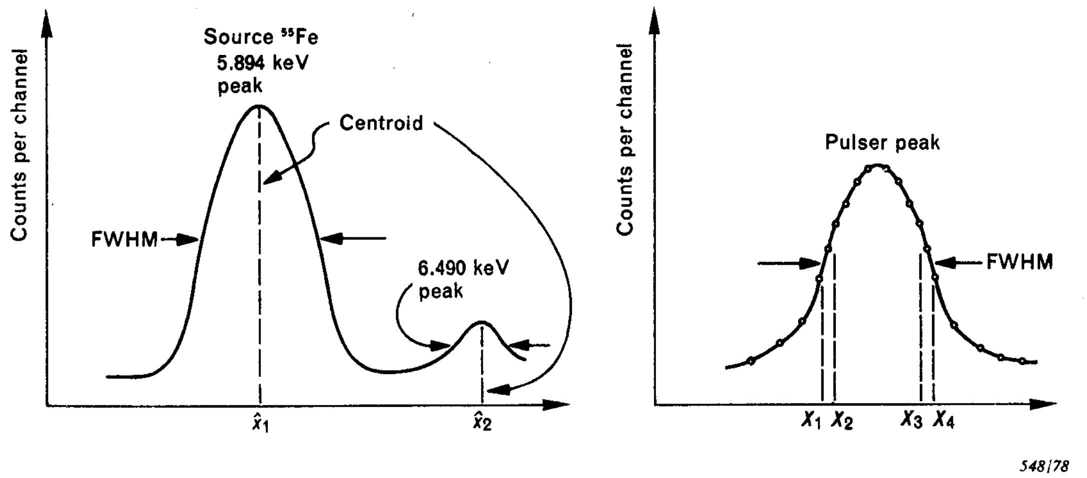
(Refer to IEC Publication 430, Clause 4, for additional information.)

## 12. Full width at half maximum (FWHM) and full width at tenth maximum (FWTM) of the peak

The FWHM and FWTM are determined by measuring the width of the spectral peak at one-half and one-tenth the maximum ordinate on a plot of $(N_x - B_x)$ versus $X$. (Additional information is available in IEC Publication 430.)

## 13. Alternative method for determination of FWHM and peak centre (centroid)

An alternative method for determination of FWHM and peak centre (centroid) is to use linear interpolation between channels or curve fitting with interpolation and to consider the peak location (or centroid) to correspond to the point midway between the half-height points that define the FWHM. This is illustrated by reference to Figure 9 that shows an example of an analyzer display for calibration and measurement of noise linewidth. Linear interpolations are made between channels $X_1$ and $X_2$ and between $X_3$ and $X_4$ in Figure 9.




Channels

Pulse height distribution using a source

Channels

Pulse height distribution using a pulse generator

FIG. 9. — Typical analyzer display for noise measurement.

# SECTION TWO — NOISE LINEWIDTH MEASUREMENTS

## 14. Noise measurement by pulse height distribution

The system noise, excluding the charge collection statistics, can conveniently be measured in units of energy. For a self-contained room temperature preamplifier, the noise linewidth measurement can be used to determine the preamplifier noise contribution. With a cryogenic system, where the first stage of the preamplifier is not accessible, the noise is also a function of some of the detector parameters. The capacitance of the detector and the leakage current through the detector are present when the cryogenic preamplifier is tested and therefore influence the noise measurement.

The preferred method of noise linewidth determination utilizes a known radioactive source (or sources) for calibration of the analyzer. After calibration of the analyzer in terms of energy per channel, a pulser is used to determine system (or preamplifier) noise linewidth. The advantage of

this method is that no knowledge of capacitor values or pulse generator calibration is needed. System gain and input must be selected so that the peaks accumulated in the analyzer for calibration and linewidth measurement have a full width at half maximum (FWHM) value of at least 20 channels and a minimum of 10 000 counts in the maximum count channel for each peak. The preamplifier (or preamplifier-detector system) is connected as indicated in Figure 3, page 13. If the radiation source has two (or more) distinct peaks of known energy, the calibration of the analyzer is readily determined, the difference between the energies of two peaks divided by the number of channels between the centroids of the peaks will yield the calibration of the analyzer in energy per channel. This calibration is valid until the effective system gain is changed. Typical sources used for calibration are Iron 55 (5.894 keV, 6.490 keV X-rays), and Americium 241 (5.443 MeV, 5.486 MeV alphas) for silicon detectors, and Cobalt 60 (1.17 MeV, 1.33 MeV gamma rays) for Germanium detectors. Care should be taken to ensure that the peaks are accumulated within the linear operating range of the system. After the system has been calibrated, the source should be removed and the pulser used to inject charge into the preamplifier*. The FWHM value, expressed in channels, of the analyzer peak resulting from the pulse generator alone is then determined. The noise linewidth in units of energy is determined by multiplying the calibration in energy per channel by the number of channels in the FWHM of the pulse generator peak.

When the noise linewidth for a preamplifier or system is specified, the method of calibration shall be stated, and the amplifier peaking time shall be stated. When a self-contained preamplifier is being specified, the noise linewidth shall be specified for zero external capacitance, and the noise versus capacitance curve shall also be provided. The noise linewidth shall be given in units of energy referred to a specified detector material.

An alternate method of measuring the noise linewidth is the method of using a calibrated pulse generator. If two well separated peaks are accumulated in the analyzer from two runs of a precision pulse generator the noise linewidth in units of charge is given as:

$$\Delta_Q = \frac{V_{p1} - V_{p2}}{\hat{x}_1 - \hat{x}_2} C_c \, \Delta_N$$

where:

$\hat{x}_1$ and $\hat{x}_2$ are the channel numbers of the centroids of the respective peaks due to pulse generator outputs $V_{p1}$ and $V_{p2}$, $C_c$ is the capacitance, in farads, of the calibration capacitor, and $\Delta_N$ is the FWHM of one peak expressed in channels.

The pulse generator should provide signals of the form shown in Figure 2, page 11, where the rise time $t_{ri}$ should be no more than 20% of the shortest differentiating time constant in the main amplifier, and the decay time constant $\tau_d$ should be such that the pulse height $V_p$ does not drop more than 2% in the time required for the output pulse of the main amplifier to reach its peak. A suggested specification is that $t_{ri}$ be $< 20$ ns, and $\tau_d$ be $> 100$ µs. The precision calibration capacitor $C_c$ in series with the precision pulse generator should preferably be of the three-terminal type; that is, the capacitance is measured between two insulated terminals, and the third terminal (connected to an electrostatic shield surrounding the capacitor) is grounded. A highly accurate measurement of the capacitance between the two isolated terminals may be obtained with a capacitance bridge.

The value of any built-in calibrating capacitor in the preamplifier may be determined by comparison with this precision, three-terminal capacitor. A suggested value of $C_c$ is 1 pF.

* The pulse generator amplitude must be adjusted so that the signals are within the linear operating range of the system.

If a monoenergetic source is available, the noise linewidth can be obtained directly in energy, provided a precision pulse generator is used. The peak due to the source is accumulated in the analyzer, and the source is removed. The pulse generator amplitude control is then set so that its reading corresponds to the energy of the source. The output is adjusted by means of the normalization control so that the channel location of the centroid of the pulse generator peak coincides with that of the source peak. Calibration of the pulse generator having been accomplished, the normalization control is not moved, but the output pulse is adjusted to correspond to another energy. The shift in output must be such that two distinct peaks are obtained. The calibration of the analyzer is obtained as discussed in the preferred method; and the pulse generator peak FWHM gives the preamplifier (or system) noise linewidth. If in the determination of noise linewidth a conversion is made from units of energy to charge or vice versa, the conversion coefficient used shall be stated.

## 15. Noise measurement by oscilloscope and r.m.s. voltmeter

The noise in a complete amplifier system can be measured by means of an oscilloscope, and a root-mean-square (r.m.s.) voltmeter. A test set-up is shown in Figure 3, page 13, where the multi-channel analyzer is replaced by an r.m.s. voltmeter. A charge pulse is applied to the preamplifier. The input charge pulse may be obtained from a source of known energy or from a calibrated pulse generator. After the output pulse amplitude has been measured, the input signal is removed. The r.m.s. noise voltage $e_{no}$ is indicated on a voltmeter having a flat frequency response extending to at least ten times the centre frequency of the amplifier pulse-shaping network and having true r.m.s. response.

If a voltmeter that responds to the average of the rectified input signal is used, the scale reading should be multiplied by 1.13 to correct for sinewave calibration. A suggested minimum 3 dB band-width for the true r.m.s. voltmeter is 10 MHz and in addition, the voltmeter should have a crest factor of at least 4. *This method of noise measurement cannot be used if a BLR or biased amplifier is in the system.*

The system (or preamplifier) noise linewidth is given in units of energy by:

$$\Delta_E = 2.355 \frac{E}{V_a} e_{no}$$

The system (or preamplifier) noise linewidth is given in units of charge by:

$$\Delta_Q = 2.355 \frac{V_p}{V_a} C_c e_{no}$$

Conversion can be made between $\Delta_E$ and $\Delta_Q$ by:

$$\Delta_Q = \frac{q}{\varepsilon} \Delta_E$$

where $q$ is the charge of an electron and $\varepsilon$ is the average energy required to form one hole-electron pair in the detector material used. The values of $\varepsilon$ for silicon at 300 K and 90 K are approximately 3.6 and 3.8 eV per hole-electron pair, respectively. A typical value of $\varepsilon$ for germanium at 77 K is 2.97 eV per hole-electron pair.

## SECTION THREE — PREAMPLIFIER NOISE PERFORMANCE

### 16. Noise as a function of amplifier shaping

The noise performance of a preamplifier can be measured by the techniques outlined in Section Two if the preamplifier output is processed by an amplifier-filter system specified as outlined in Clause 10. A typical plot is shown in Figure 10.

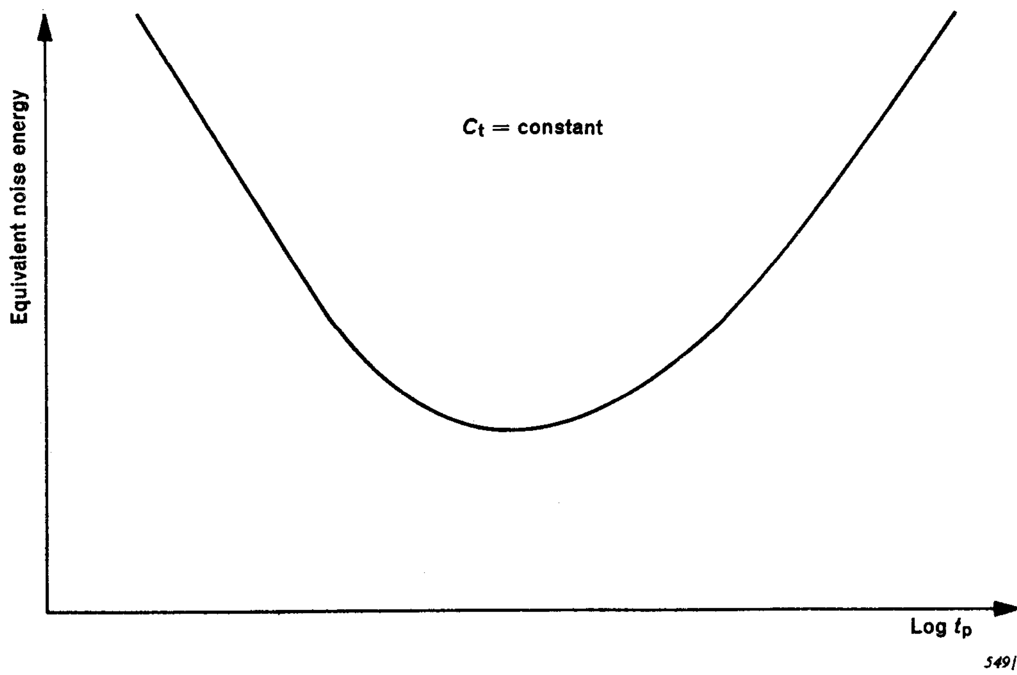



FIG. 10. — Noise versus amplifier peaking time $t_p$ (or time constants) for fixed external capacitive loading at preamplifier input.

When measuring preamplifier noise, it is necessary to verify that noise from the main amplifier does not substantially contribute to the results. For any given set of amplifier settings, the main amplifier contribution can be determined by measuring $e_{no}$ with and without the preamplifier connected to the main amplifier. In the latter case, the main amplifier input is shunted to ground through an impedance equal to the output impedance of the preamplifier.

### 17. Noise as a function of external capacitive loading at preamplifier input

Measurement and specification of noise by the techniques described in Clauses 14 and 15 may be stated as a function of external capacitive loading at the input of the preamplifier, if the amplifier pulse parameters are given as stated in Clause 10. Alternatively, the pulse shaping may be fixed and the equivalent noise energy may be plotted as a function of external capacitive loading. A typical plot is shown in Figure 11, page 31.

### 18. Microphonics

Mechanical vibration and shock can add noise to a spectrometer system, with the detector-preamplifier combination typically being more sensitive to microphonics than the other parts of the system. Noise of microphonic origin can be measured by mechanically shocking or vibrating

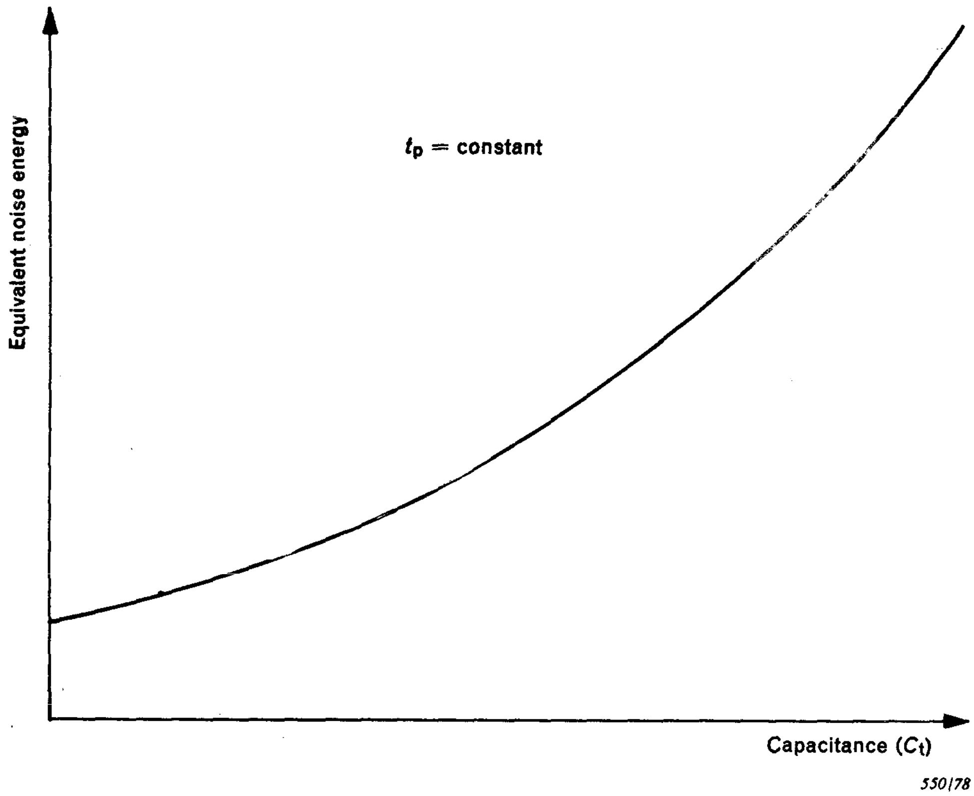



FIG. 11. — Equivalent noise versus external shunt capacitance $C_t$ at preamplifier input for fixed amplifier peaking time (time constant).

the system as needed for a particular application. To test for microphonics, the preamplifier must be connected for normal operation, and the maximum rated detector bias voltage must be applied to the detector. The preamplifier, or system, output noise can be measured as described in Section Two.

## 19. Maximum detector bias voltage

Large volume Ge(Li) detectors require bias voltages up to several thousand volts. The preamplifier input connector and the coupling capacitor (d.c. detector coupling left out of consideration) should not add noise to the system at the maximum rated detector bias voltage for the preamplifier under consideration. When performing the noise measurements described in Section Two the maximum rated detector bias network voltage must be applied. Any time period necessary for establishing charge equilibrium in the detector bias network must be stated.

# SECTION FOUR — MAIN AMPLIFIER NOISE

## 20. Equivalent noise referred to input

The noise contribution of the main amplifier to the system noise can be assessed by determining the equivalent noise voltage $e_{ni}$ referred to the input of the main amplifier. A voltage pulse $V_p$ from a precision pulse generator is applied directly to the input of the amplifier under test, and the peak

value of the output pulse from the amplifier $V_a$ is measured on an oscilloscope. After the pulse generator is removed, the input terminal of the amplifier is shunted to ground through an impedance equal to the output impedance of the preamplifier and this value shall be stated. Where the output impedance of the preamplifier to be used is not known, the main amplifier shall be tested with 100 Ω from amplifier input to ground. The output noise voltage $e_{no}$ of the amplifier is measured on a true r.m.s. voltmeter. The equivalent noise referred to the input $e_{ni}$ is defined as:

$$e_{ni} = e_{no} \frac{V_p}{V_a}$$

The signal parameters of Clause 10 and the range of gain settings over which the specified noise voltage applies shall be stated.

## SECTION FIVE — PULSE HEIGHT LINEARITY

### 21. Integral nonlinearity measurement by the bridge method

An ideal pulse amplifier system produces an output pulse with an amplitude proportional to that of the input pulse. Deviation from exact proportionality is described as nonlinearity. Integral nonlinearity (INL) is the maximum deviation from linearity expressed as a percentage of the specified maximum linear output.

The measurement can be carried out with the test arrangement of Figure 12. The pulse from the precision pulse generator travels three paths: directly to the oscilloscope synchronizing input, to the resistive summing network, and through the attenuators and the amplifier system to the second terminal of the resistive summing network.

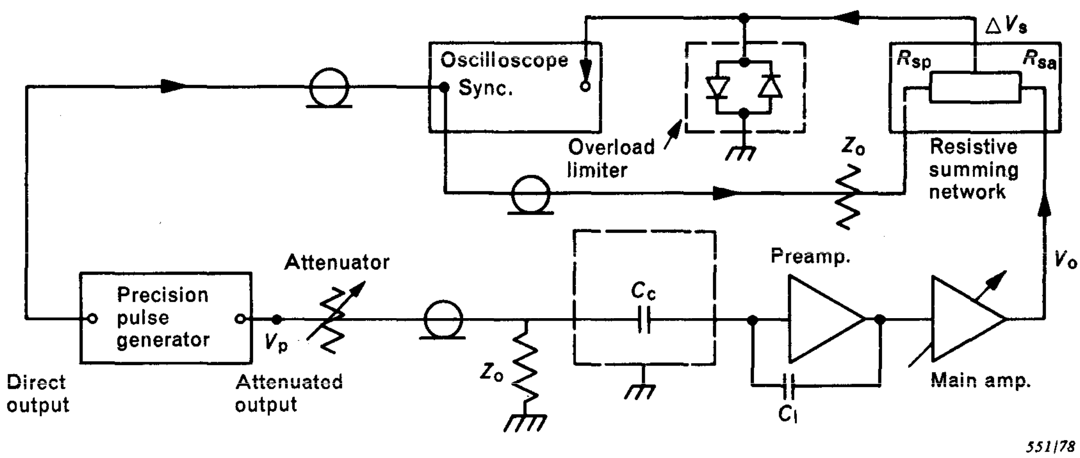



FIG. 12. — Measurement of integral nonlinearity by the bridge method.
(Attenuator may be within pulse generator.)

Suitable pulse generators have a direct output and an attenuated output as shown in Figure 1, page 11, and Figure 12 which are driven from a zero-impedance point in the circuit to prevent interaction from the loads. If the pulse generator has a zero impedance output, then all three loads can be driven from this output.

Polarity inversion must occur in one of the paths, so that the signals at the summing point subtract. If the amplifier or preamplifier does not provide phase inversion, a separate phase inverter (for example, a suitable pulse transformer) must be inserted in one path. An attenuator may be required between the main amplifier output and the resistive summing network to reduce the pulse amplitude of the main amplifier at maximum output level to that of the precision pulser. Figure 13 displays a typical waveform of $V_s$. *The impedance seen from the summing point to the pulse generator must be equal to the impedance seen from the summing point to the amplifier.*

The difference in the waveform of the pulser and the amplifier causes a large initial excursion that will overdrive the oscilloscope when the gain is high enough to measure INL in the fractional percentage range. This overload effect on the oscilloscope can be reduced by using an overload limiter as shown in Figure 12, page 33.

The overload limiter may, for example, consist of low-capacitance high-frequency semiconductor diodes (such as Schottky barrier diodes) connected as shown in Figure 12.

The measurement is carried out by setting the main amplifier gain to its maximum and adjusting the pulse generator amplitude and the attenuator setting until the amplifier output equals the maximum specified linear output $V_o$ (max.) specified by the manufacturer and $V_s$ equals zero. The pulse is then reduced, leaving all other conditions (including attenuator setting) fixed to allow plotting of $V_s$ as a function of amplifier output amplitude.

*Note.* — INL will depend on amplifier gain and pulse shaping arrangements.

For a given choice of amplifier settings and where $R_{sp}$ and $R_{sa}$ of Figure 12 give an attenuation factor of two, INL is given by equation:

$$\text{INL} = \frac{200\,|\Delta V_s|\,\text{max.}}{(V_o)\,\text{max.}} \quad \text{(in per cent)}$$

where $|\Delta V_s|$ max. is the magnitude of the maximum deviation of $V_s$ at the measurement point (usually the pulse peak), as $V_o$ is varied over the entire range from zero to $V_o$ (max.) for the particular amplifier settings.

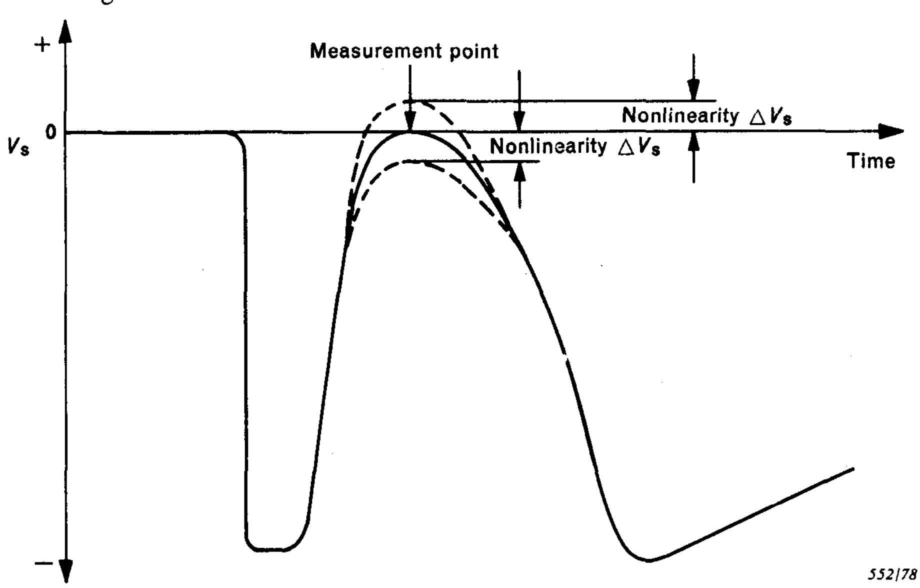



FIG. 13. — Typical waveform of $V_s$.

When characterized by a single unqualified number the INL shall not exceed that number at any amplifier setting. In the case of amplifiers intended for use with input pulses of either polarity, the linearity measurements shall be made for both positive and negative inputs. The measurements shall be made with and without inversion (where inversion is provided) and for the output polarity (or polarities) that contain pulse amplitude information.

## 22. Differential nonlinearity

Differential nonlinearity DNL is defined on page 69 by:

a) $$\mathrm{DNL} = 100 \left[ 1 - \frac{(\Delta V_o \,/\, \Delta V_p)\ (\text{meas.})}{(\Delta V_o \,/\, \Delta V_p)\ (\text{ref.})} \right] \text{ (in per cent)}$$

This definition gives the percentage departure of the slope of the plot of output versus input from the slope of a reference line, which must be stated (as indicated in Figure 14). The set-up of Figure 3, page 13, may be used to obtain a plot of output pulse amplitude versus input pulse amplitude. A typical plot is shown in Figure 14. The quantity DNL can also be measured and displayed using a

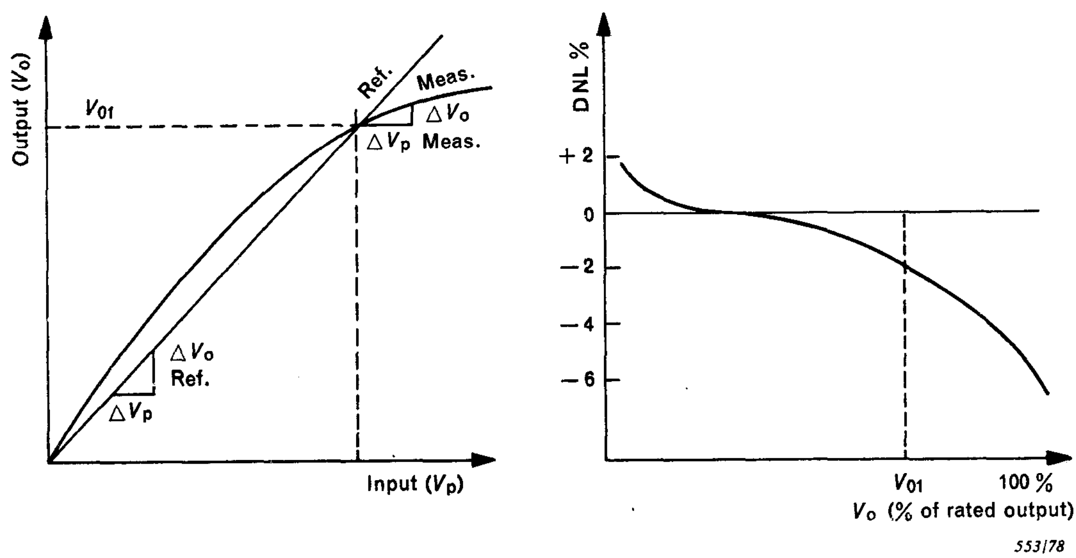



FIG. 14. — Measurement and display of differential nonlinearity (DNL).

sliding pulser whose output increases linearly with time, starting from zero. The number of counts $N_x$ in each channel of a multichannel analyzer (MCA) after correction for nonlinearity of the analyzer and sliding pulser provides a measure of DNL as in equation:

$$\mathrm{DNL} = 100 \left[ 1 - \frac{N_x}{N_{avg}} \right] \text{ (in per cent)}$$

where:

$N_x$ is the number of counts in channel $X$

$N_{avg}$ is the number of counts per channel averaged over all the channels up to the channel corresponding to the maximum rated linear output

When characterized by a single unqualified number, the DNL shall not exceed that number anywhere within the specified range. In the case of amplifiers intended for use with input pulses of either polarity, the linearity measurements shall be made for both positive and negative inputs.

If DNL is zero, the number of counts in all channels of the MCA will be equal, after correction for MCA and pulser nonlinearities.

## 23. Biased amplifier

A biased amplifier amplifies only that portion of a signal above a specified biased level ($V_t$ of Figure 15). The integral nonlinearity can be checked using a variable amplitude pulse source and a multichannel analyzer connected as shown in Figure 16. The pulse generator should have excellent amplitude setting resolution (preferably 1 part in $10^5$), and linearity better than the other system components.

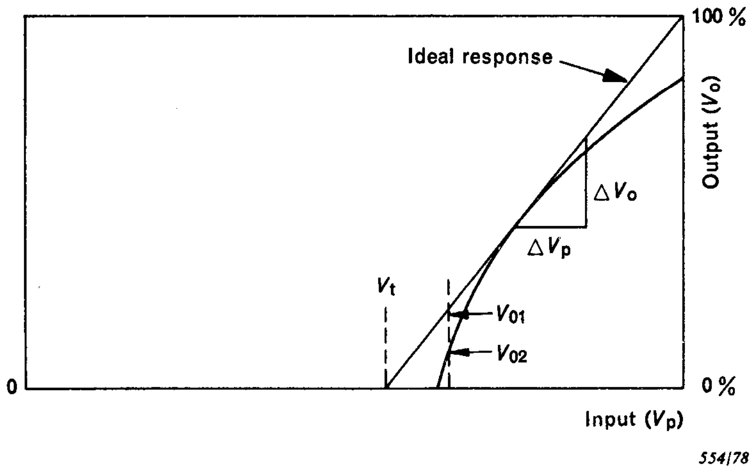



FIG. 15. — Measurement of integral nonlinearity (INL) for a biased amplifier.

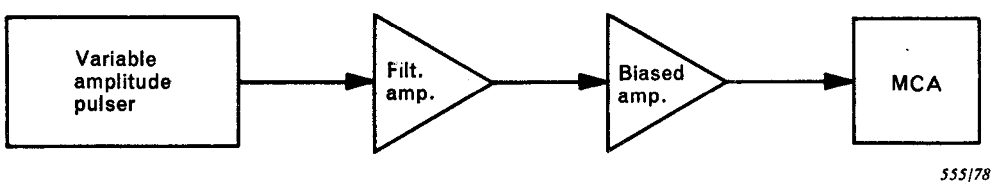



FIG. 16. — System for measuring integral nonlinearity of biased amplifiers.

To measure the integral nonlinearity, collect a spectrum in the MCA for each setting of the pulse generator as the output of the biased amplifier is varied from 0 to $V_o$ max. in small increments. Plot the pulser output voltage versus centroid channel number for each pulser setting. Figure 15 is a typical plot of output-pulse amplitude versus input-pulse amplitude. The integral nonlinearity INL of a biased amplifier is defined by:

$$\text{INL} = 100 \left[ \frac{V_{o2} - V_{o1}}{\left( \dfrac{V_t \cdot \Delta V_o}{\Delta V_p} \right) + V_o \text{ max.}} \right] \text{ (in per cent)}$$

where $V_t$ is the threshold bias.

The maximum biased amplifier nonlinearity INL usually occurs near the bias threshold.

The equation for DNL (Clause 22, equation a) is the same for biased amplifiers as for unbiased amplifiers.

SECTION SIX — COUNTING RATE EFFECTS

## 24. Experimental arrangement

The experimental arrangement for the measurement of counting rate effects or spectral distortion is shown in Figure 17. The counting rate effects on the precision pulse generator spectrum are measured in the presence of random counting rate from the *irradiated detector*.

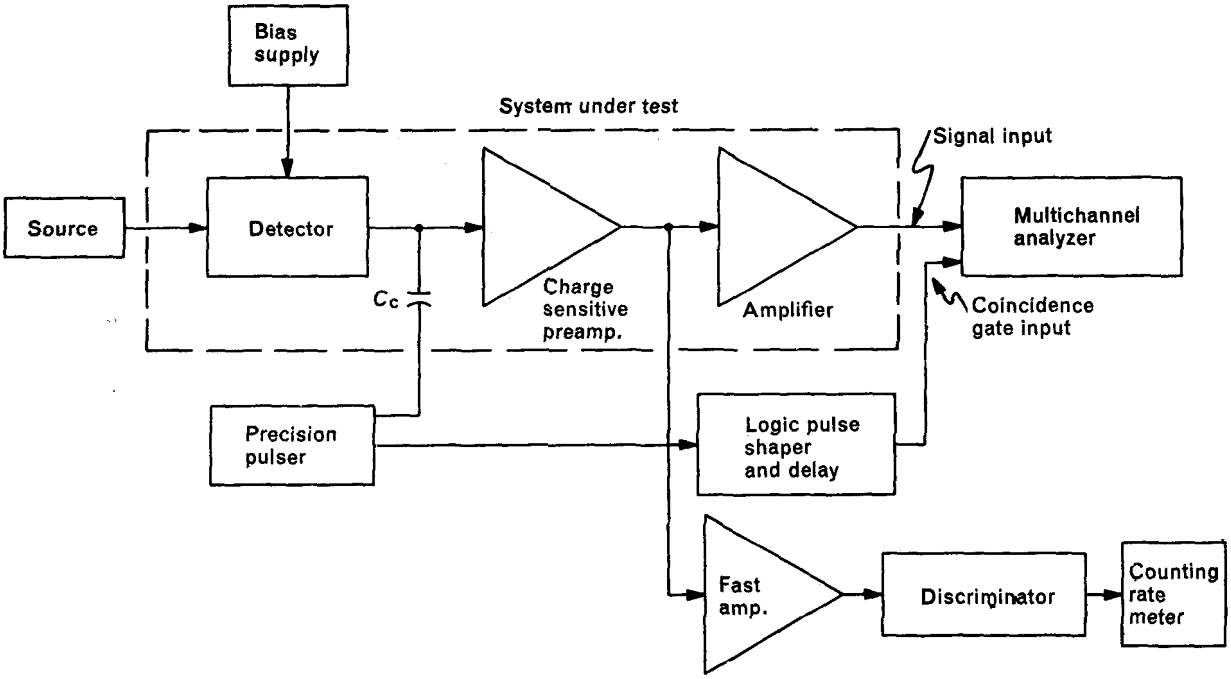



FIG. 17. — Experimental arrangement to measure spectral distortion resulting from counting rate effects.

A logic pulse shaper and delay is triggered by the pulser and generates an appropriately timed gate signal to coincidence-gate the MCA and store the pulse generator spectrum. The multichannel analyzer may be operated in the coincidence mode to avoid counting rate dependent effects in the analog-to-digital converter (ADC). It is essential that the input stages of the ADC be d.c. coupled.

The equivalent input counting rate is measured by the fast amplifier, discriminator and counting rate meter. The fast amplifier shaping time is selected for optimum resolving time and the discriminator level is adjusted to "just above" noise ($\sim 5 \times$ noise r.m.s. value).

The main problems with the counting rate effect measurements are: *a)* the difficulty of isolating the contribution of any one component of the detector-preamplifier-amplifier system: and *b)* the dependence of counting rate performance on many factors, such as signal energy, preamplifier noise, and amplifier shaping. It is therefore necessary that in the testing of one system component the other two possess superior characteristics, and that the system parameters are selected so as to approximate the conditions under which the amplifier will be used.

## 25. Signal sources and system parameters

When investigating counting rate performance, it is imperative that the preamplifier pole-zero network be properly adjusted. Also, the following parameters must be stated;

*a)* preamplifier decay-time constant;

*b)* amplifier shaping, including BLR setting;

*c)* low counting rate resolution (at a counting rate below which resolution does not change with counting rate);

*d)* radiation source and energy used for random signal source;

*e)* detector parameters: type, sensitive area dimensions, capacitance, relative efficiency, etc;

*f)* energy corresponding to pulse amplitude of the pulse generator output.

The following radiation sources are recommended for use in counting rate measurements:

| Isotope | X- or gamma-ray energy |
|---|---|
| $^{55}Fe$ | 5.894 keV, 6.490 keV |
| $^{57}Co$ | 122 keV |
| $^{137}Cs$ | 662 keV |
| $^{60}Co$ | 1.17, 1.33 MeV |

## 26. Pulse height distribution peak shift

The peak location of a pulse height distribution may exhibit dependence on total counting rate. The experimental set-up shown in Figure 17, page 41, provides a means to measure pulse height shift as a function of average counting rate for random pulse spacing in time. The precision pulse generator provides pulses of fixed input charge, which are examined by the multichannel analyzer. The analyzer is coincidence-gated for the generator pulses only. The counting rate is varied by adjusting the spacing between the radiation source and the detector and is measured with a count rate meter with the discriminator set to limit the noise count rate to less than 0.5% of the maximum specified count rate of the amplifier. At low counting rates, the radiation peak should be set at 70% of the maximum specified linear output of the amplifier, and the pulse generator pulse at 90%. The counting rate should then be increased and the shift of the pulse generator peak plotted as a function of total counting rate.

## 27. Spectral resolution versus counting rate

The set-up shown in Figure 17 is used for this measurement. The FWHM and/or FWTM of the pulse height distribution of the pulse generator peak is measured. The source and pulse generator peaks should be set at 70% and 90%, respectively, of the maximum specified output range as in Clause 26. For amplifiers containing other functions, such as pile up rejection, that reduce spectral distortion by limiting the output counting rate, the performance must be specified as a function of both input and output counting rates. Peak shift and resolution shall be determined for a low counting rate (about 1 000 counts per second) and a high (maximum) counting rate specified by the manufacturer. In addition, peak shift and resolution shall be determined for other counting rates as specified. The discriminator should be set as in Clause 26.

## SECTION SEVEN — OVERLOAD EFFECTS

### 28. General

The behaviour of an amplifier to an input pulse that drives the amplifier far into the overload region depends on many factors. The order in which different sections of the amplifier overload may depend on the gain control and time constant settings. All of the gain control settings and pulse shape parameters shall be stated when the overload recovery time is specified; otherwise, it is assumed that the specification applies for all gain and filter networks combinations available in the unit. Amplifiers having adjustable pole-zero networks must have the networks adjusted precisely before overload tests are performed.

### 29. Amplifier gain recovery time

An amplifier is judged to be recovered from overload when the output waveform returns to the baseline and remains within a band about the baseline of ±1% of the maximum specified output voltage and the gain for small signals has returned to normal. After an overload pulse, the output

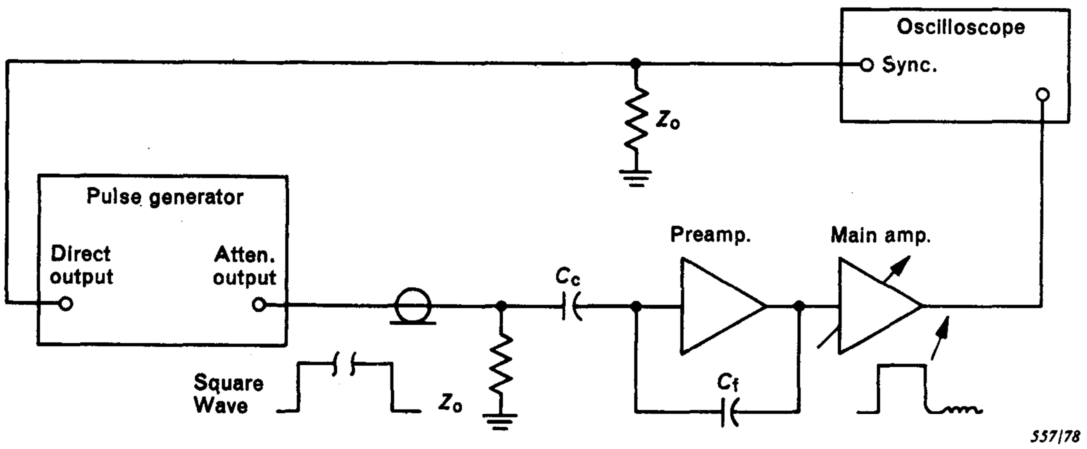



FIG. 18. — Measurement of preamplifier gain recovery time.

waveform of some amplifiers returns to the baseline sooner than the gain returns to normal. Return to normal gain may usually be judged by the reappearance of full noise on the oscilloscope trace. The test arrangement shown in Figures 18 and 19, page 47, permits a quick measurement of preamplifier and amplifier recovery time after an overloading pulse. One may insert "artificial noise" at the input along with the overloading pulse in order to be certain when the amplifier gain has returned to normal. The output of the sinewave generator is mixed with the voltage pulse from the precision pulse generator through a d.c. coupled summing amplifier.

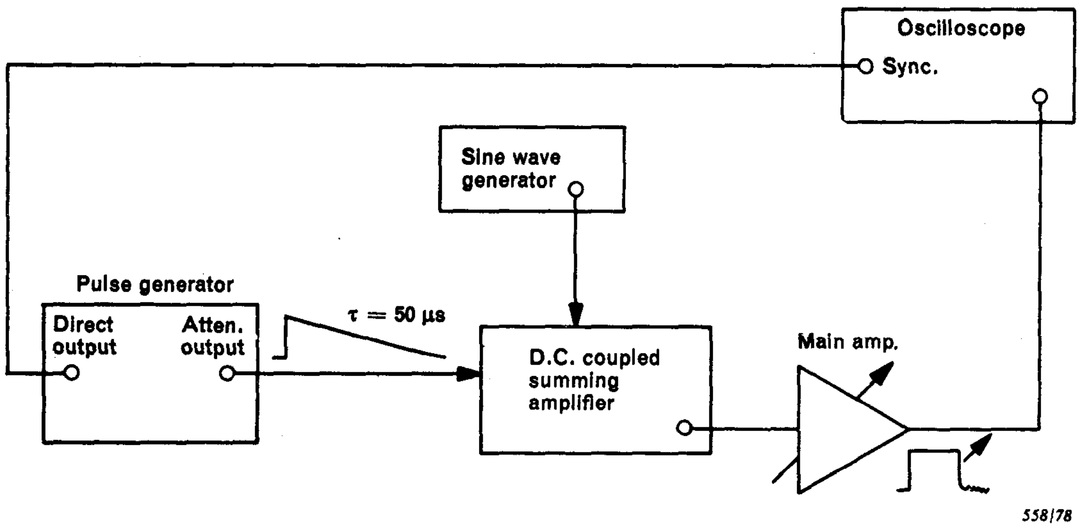



FIG. 19. — Measurement of main amplifier gain recovery time.

An example of such overload behaviour is illustrated in Figure 20. Note that the reappearance of the noise signal on the trace clearly shows when the amplifier gain has returned to normal. The waveform returns to the baseline very quickly after the overload pulse, but the gain does not recover until much later. Tests shall be made with overload factors of 100 and 1 000 at several time constant settings.

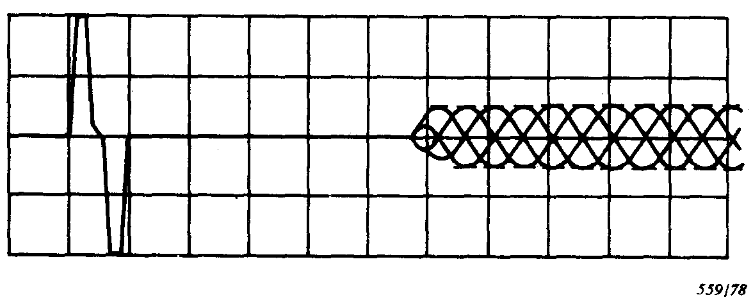



FIG. 20. — Typical display of amplifier gain recovery after an overloading pulse, using the technique of Figure 18, page 45.
(Double delay line shaping amplifier.)

## SECTION EIGHT — PULSE HEIGHT DEPENDENCE ON RISE TIME

### 30. General

The height of pulses from the main amplifier (for constant input charge) will be affected in two ways by changes in capacitive loading on the input of the preamplifier. Firstly, the rise time in a charge sensitive preamplifier is increased by capacitive loading of the input, because the feedback factor is reduced. This increase in rise time will result in a decrease in output-pulse amplitude from the main amplifier because of the main amplifier pulse-shaping networks. Secondly, the preamplifier output-pulse amplitude is also reduced by capacitive loading, since the dynamic input capacitance is finite

## 31. Input capacitive loading effects on the preamplifier output pulse

The effects of capacitive loading at the preamplifier input on the output-pulse amplitude and rise time can be evaluated by a test arrangement similar to that of Figure 21. The output-pulse amplitude is measured for several values of $C_t$ and expressed as a percentage of the pulse amplitude for $C_t$ equal to zero.

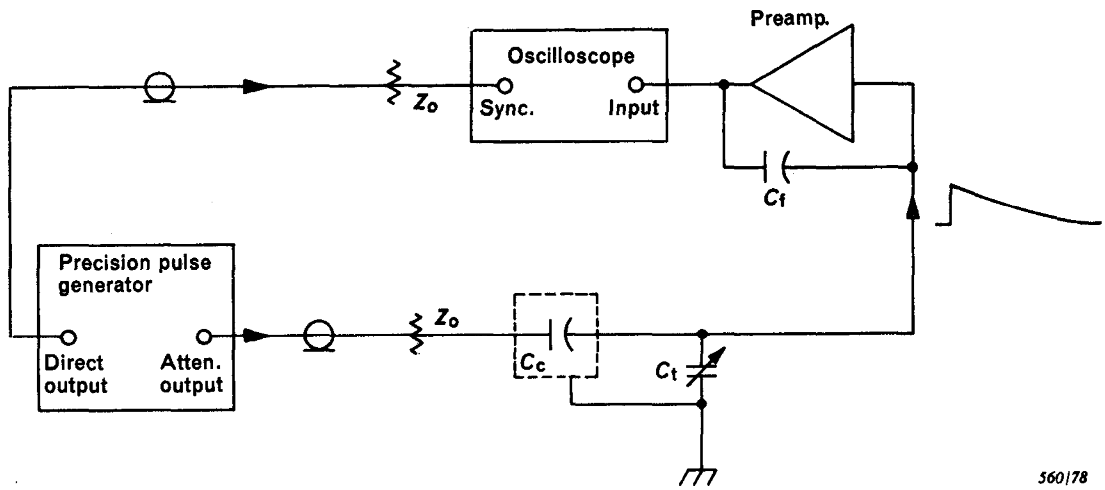



FIG. 21. — Measurement of capacitive loading effects on the preamplifier.

The rise time, $t_{r1}$, of the preamplifier output pulse for the precision pulse generator at the input is defined as the time required for the pulse to rise from 10% to 90% of its peak value and is measured as a function of $C_t$.

## 32. Influence of charge-pulse duration on pulse height

Some types of semiconductor detectors exhibit long charge collection times. This may reduce the amplifier output pulse height if the charge collection time is comparable to the shaping network time constants or integrating time for a gated integrating amplifier. The charge collection time $t_c$ of

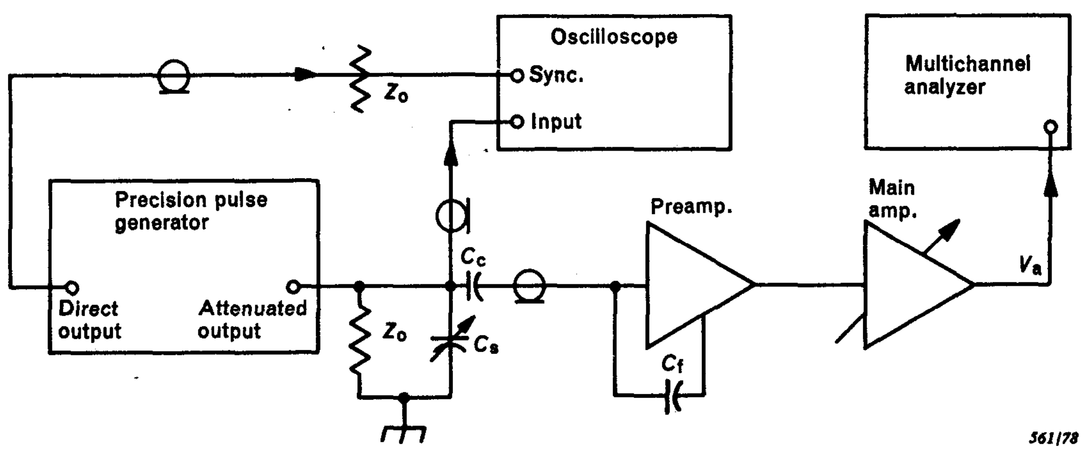



FIG. 22. — Simulation of non-zero charge-pulse rise time.

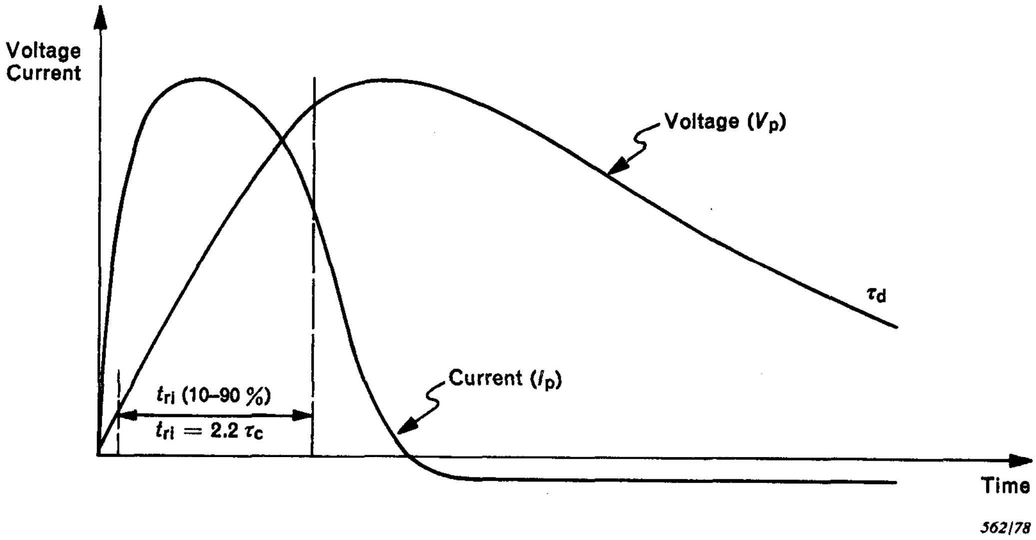



FIG. 23. — Voltage and current waveforms present in the circuit of Figure 22.

a detector can be simulated by an RC network of time constant $\tau_c$. The circuit arrangement of Figure 22, page 49, gives an output pulse that approximates the current pulse from a detector by increasing the rise time of the pulse from a precision pulse generator. The resulting waveforms are shown in Figure 23. If a particular value of $\tau_c$ is desired, then $C_s$ is given by:

$$C_s = \frac{\tau_c}{Z_o/2}$$

SECTION NINE — PULSE HEIGHT STABILITY

33. **Line voltage variations**

The test set-up is identical with that shown in Figure 12, page 33, except that the line voltage is variable. Set the line voltage at its nominal value and adjust the amplifier output so that $V_s$ equals zero at the measurement point. Observe the maximum deviation of $V_s$ as the line voltage to the power supply for the amplifier is varied over a range of 88% to 110% of the nominal operating voltage while all other conditions are maintained constant. This variation is often expressed in percentage for a given line voltage change and is obtained by multiplying the change in $V_s$ by 2 and dividing that quantity by the amplifier output voltage at nominal line voltage. A similar test may be performed with a biased amplifier in the system as in Figure 16, page 39. In this case, the pulse generator should be adjusted to give maximum rated output voltage from the biased amplifier at the desired gain and bias level setting. Spectra should be obtained at 88% and 110% of nominal line voltage to the power supply. Output voltage stability $S_L$ (pulse height variation) over a +10%, −12% line voltage range is given by:

$$S_L = 100 \frac{S \cdot \Delta_{CH}}{A \cdot V_{in}} \text{ (in per cent)}$$

where $\Delta_{CH}$ is the number of channels between the two MCA peaks, $S$ the calibration of the MCA in volts per channel, $A$ the gain of the biased amplifier and $V_{in}$ the input voltage to the biased amplifier. It is important in this test to have the pulse generator power supply separate from that of the amplifier under test.

*Note.* — In the case of modular systems where the power supply is separate, this becomes principally a test of the power supply performance.

### 34. Temperature effects

For this test, the amplifier is placed in an environmental test chamber. The changes in pulse height produced by changes of the ambient air temperature, with other conditions maintained constant, can be expressed as a temperature coefficient of pulse height; for example 0.01% per degree Celsius.

Many amplifiers have d.c. coupled output terminals and pulse height shifts can be caused by gain changes or d.c. level shifts. When applicable, both of these parameters shall be measured and specified. These measurements will be made over a specified temperature range measured at no greater than 10 °C increments. The specification given must be valid for all 10 °C increments within the specified temperature range.

### 35. Gain stability

The test set-up is identical with that shown in Figure 12, page 33. The precision pulse generator output is kept constant instead of being varied as in Clause 21. Fast-recovery diodes may be used as limiters at the oscilloscope input from the resistive summing network in order to minimize the effects of overdriving the oscilloscope. Biased amplifiers may be evaluated for stability by the system shown in Figure 16, page 39. Gain variations can be determined by observing the peak centroid shift in the MCA. Test conditions should be maintained constant and the maximum gain variations noted over an extended period of time which shall be stated.

## SECTION TEN — CROSSOVER WALK *

### 36. Crossover walk versus output amplitude

Timing information can be obtained from the crossover time of a bipolar pulse. The amount that the crossover time varies, or "walks", with changes of some parameters is a measure of the usefulness of the amplifier for certain timing applications. The apparatus shown in Figure 24, page 55, permits measurement of crossover walk versus output amplitude. The channel A amplifier system gain is held constant. The precision attenuator in channel B is adjusted to obtain maximum rated linear output amplitude from the amplifier under test.

The variable delay in channel A is adjusted so that the zero crossover point of the signal in channel B occurs at the centre of the oscilloscope display. The attenuator of channel B is varied throughout the linear dynamic range of the amplifier output and the maximum crossover time shift is observed on the oscilloscope.

The attenuator in channel B may be within the pulse generator and the delay in channel A may be in the oscilloscope if it has a dual time base. When crossover walk is specified, the dynamic range associated with that specification will also be stated.

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* See definition, page 69.

## 37. Crossover walk versus gain control setting

The apparatus of Figure 24 is also used for this test. The crossover time is measured by the techniques described in Clause 36. The crossover time is noted, and the walk is noted over the entire range of the fine- and coarse-gain controls on the amplifier. The channel B attenuator and amplifier gain controls are varied to maintain a substantially constant amplitude at the channel B oscilloscope input. The total crossover walk over the entire range of fine- and coarse-gain control settings shall be stated.

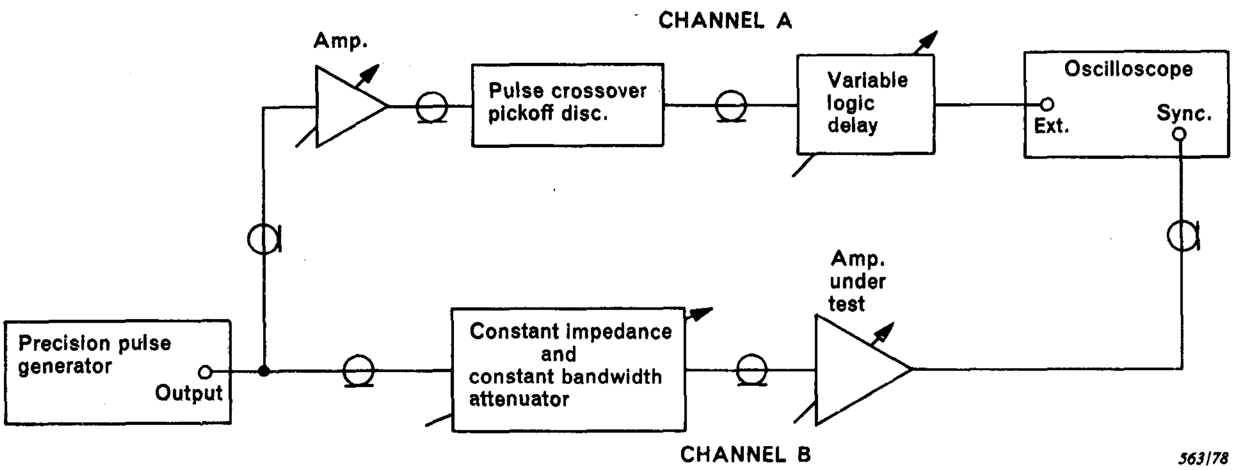


FIG. 24. — Measurement of crossover time walk.

## 38. Range of pole-zero cancellation network in main amplifier

Most main amplifiers have a built-in and adjustable pole-zero cancellation network to eliminate undesirable undershoot which is caused by the decay of the preamplifier output pulse and the differentiation in the main amplifier. The preamplifier output pulse decay time constant may differ over a wide range from type to type. The main amplifier pole-zero network should be able to cancel the decay time constant of the preamplifier in use. It is therefore desirable to know the pole-zero cancellation time constant range of the main amplifier, which can be measured as follows. Drive the main amplifier with a pulse generator having an adjustable decay time constant and observe the main amplifier output pulse with an oscilloscope. Find, by varying the decay time of the pulse generator, the minimum and maximum decay time of the input pulse which can be cancelled by adjusting the pole-zero network of the main amplifier. Complete cancellation is obtained when the undershoot of the output pulse is completely compensated. The manufacturer shall state the time constant range of the pole-zero network of the main amplifier.

An alternative method is to drive the differentiator network having pole-zero cancellation in the main amplifier with a square wave. The differentiator and pole-zero cancellation network is assumed to be as depicted in Figure 25, page 57.

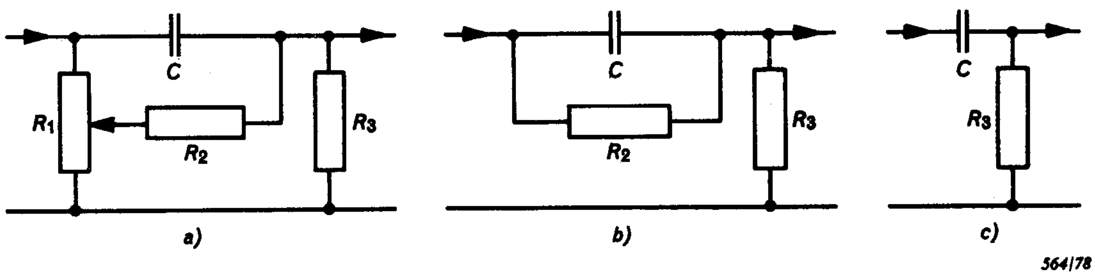


FIG. 25. — *a)* Differentiator and pole-zero cancellation network ($R_1 \ll R_2$).

*b)* Equivalent circuit for compensation of shortest decay time constant of input pulse.

*c)* Equivalent circuit for compensation of longest decay time constant of input pulse.

For a unit step input signal, the output signal for the circuit of Figure 25 is expressed by the following formula:

$$V_o = V_{in} \frac{R_3}{R_2 + R_3} + V_{in} \frac{R_2}{R_2 + R_3} \cdot e^{-\left[\frac{t}{C\left(\frac{R_2 R_3}{R_2 + R_3}\right)}\right]}$$

The output waveform is shown in Figure 26:

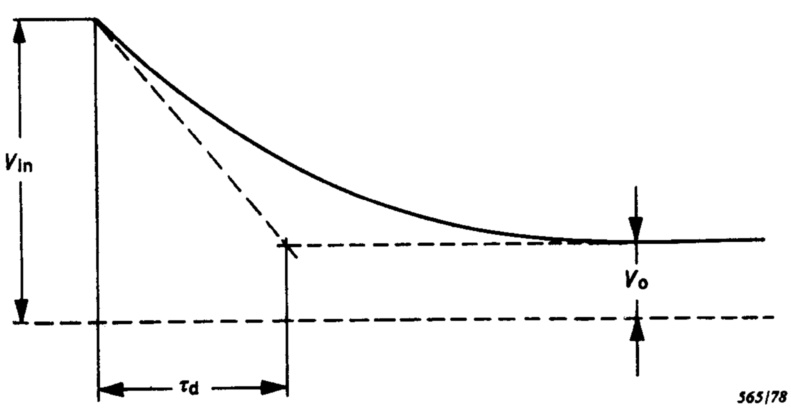


FIG. 26. — Output pulse of the circuit shown in Figure 25 *b)* when driven by a unit step input pulse.

The minimum compensative decay time constant is determined by time constant $CR_2$. From an oscillogram, the time constant

$$\tau_d = C \frac{R_2 R_3}{R_2 + R_3} \text{ as well as the ratio } \frac{R_3}{R_2 + R_3}\text{, being } \frac{V_o}{V_{in}} \text{ can be read.}$$

From the values thus obtained, the value of $CR_2$ can be calculated. In most cases, the value of $\tau_d$, stated by the main amplifier manufacturer, can be used. The maximum compensative decay time constant for the network of Figure 25 *a)* is infinitely long.

# APPENDIX

## SYMBOLS AND GLOSSARY

### 1. Symbols

$A$ = amplifier gain

$A_C$ = preamplifier conversion gain

$A_O$ = preamplifier open loop gain

BLR = baseline restorer

$B_x$ = background counts in channel $X$

$C$ = electrical capacitance

$C_c$ = calibrated capacitor used to couple pulse generator to circuit under test

$C_f$ = feedback capacitor for charge-sensitive preamplifier

°C = degrees Celsius

$C_s$ = shunt capacitance used to simulate various charge collection times

$C_t$ = value of external shunt capacitor used to determine effect of capacitance loading of the preamplifier

$\Delta$ = FWHM of a monoenergetic spectral peak

$\Delta_{CH}$ = number of channels between the centroids of two MCA peaks

$\Delta_E$ = FWHM noise linewidth in unit of energy

$\Delta_N$ = FWHM noise linewidth in number of channels

$\Delta_Q$ = FWHM noise linewidth in unit of charge

$\Delta_V$ = FWHM noise linewidth in volts

$\Delta V_a$ = change in amplifier output voltage

$\Delta V_p$ = change in pulse generator output voltage

DNL = differential nonlinearity of an amplifier

$E$ = energy of a particle

$e$ = base of natural logarithms

$\varepsilon$ = average energy required to form one hole-electron pair

$e_n$ = root-mean-square value of noise voltage

$e_{ni}$ = equivalent root-mean-square value of noise voltage referred to the input of the amplifier under test

$e_{no}$ = root-mean-square value of noise voltage at the output of the system

FWHM = full width at half maximum

FWTM = full width at tenth maximum

K = Kelvin, unit of thermodynamic temperature (degrees)

INL = integral nonlinearity of an amplifier

MCA = multichannel analyzer

$N_{avg}$ = average number of counts in all channels of a multichannel pulse-height analyzer spectrum

$N_x$ = number of counts in channel $X$ of a multichannel pulse-height analyzer spectrum

$Q$ = electric charge

$q$ = electron charge

$R$ = electrical resistance

$R_f$ = resistor in parallel with $C_f$

r.m.s. = root-mean-square

$R_{sa}$ = resistor placed in summing network, between the sumpoint and the amplifier

$R_{sp}$ = resistor placed in summing network, between the sumpoint and the pulser

$S$ = MCA calibration in volts per channel

$S_L$ = amplifier system stability (pulse height variation) over specified line voltage range

$t_c$ = charge collection time in a detector

$t_{dl}$ = delay (retard) time between start of amplifier input pulse and start of amplifier output pulse (departure from defined zero)

$t_f$ = fall time of a pulse. The time required for the pulse to go from 90% to 10% of its peak value

$t_p$ = peaking time

$t_{ri}$ = rise (ascent) time of a pulse. The time required for the pulse to go from 10% to 90% of its peak value

$t_w$ = time elapsed from the first crossing to the second crossing of the defined pulse width — defined zero level

$\tau$ = time constant

$\tau_c$ = time constant of a CR network used to simulate the rise of a pulse from a radiation detector

$\tau_d$ = time constant for decay of a pulse

$\tau_f$ = time constant for preamplifier feedback network

$V$ = electrical voltage

$V_a$ = amplitude of pulse at amplifier output

$V_{in}$ = amplitude of pulse at amplifier input

$V_o$ = amplitude of the voltage output signal of an amplifier during measurement of amplifier linearity

$V_p$ = amplitude of the voltage pulse from a precision pulse generator

$V_t$ = threshold bias voltage of a biased amplifier

$V_s$ = error voltage at the summing point during linearity check

$X$ = channel number

$\hat{x}$ = peak centre channel (centroid of symmetrical portion of peak)

$Z_o$ = characteristic impedance

## 2. Glossary

*Amplifier gain recovery time*

The period of time elapsing from the application of a standard overloading pulse (see Figure 20, page 47) to the instant at which steady state conditions for gain and baseline have recovered to normal.

*Baseline (at pulse peak)*

The instantaneous value that the voltage would have had at the time of the pulse peak in the absence of that pulse.

*Bias resistor (of a semiconductor radiation detector)*

The resistor through which bias voltage is applied to the detector.

*Bias voltage (of a semiconductor radiation detector)*

The voltage applied to the detector to produce the electric field to collect the signal charge.

*Capacitance (of a semiconductor radiation detector)*

The capacitance between terminals of the detector as measured with small signals under specified conditions of bias and frequency.

*Charge collection time (of a semiconductor detector)*

By convention, the time interval for the integrated current due to the charge collected in the semiconductor detector, after the passage of an ionizing particle, to increase from 10% to 90% of its final value (I.E.V. 391-10-59).

*Clip, clipping*

A limiting operation such as 1) use of a high-pass filter (see differentiated), or 2) a non-linear operation such as diode limiting of pulse amplitude.

*Compensated semiconductor detector*

A semiconductor detector in which one type of impurity or imperfection (for example, donor) partially cancels the electric effects of the other type of impurity or imperfection (for example, acceptor).

*Constant fraction discriminator*

A pulse amplitude discriminator in which the threshold for acceptance of a pulse is a constant fraction of the peak amplitude of the pulse.

*Note.* — Its purpose is to produce an output pulse delayed with respect to the input pulse by a time interval essentially independent of the input pulse amplitude.

*(Counting) ratemeter*

A sub-assembly designed to provide a continuous indication of the average counting rate (I.E.V. 391-11-44).

*Crest factor (of an average reading or root-mean-square voltmeter)*

The ratio of (1) the peak voltage value that an average reading or root-mean-square voltmeter will accept without overloading to (2) the full scale value of the range being used for measurement.

*Crossover time (of a pulse)*

The instant at which the waveform of a bipolar pulse passes through a designated level.

See also: Zero crossover time.

*Crossover walk (of a pulse)*

The variation of the crossover time for some variable, such as amplitude. See also: Zero crossover walk.

*CR — RC shaping*

The pulse shaping present in an amplifier that has a simple high-pass filter and a simple low-pass filter, each consisting of a capacitor and a resistor.

*Dead layer (of a semiconductor detector)*

A layer of a semiconductor detector in which no significant part of the energy lost by particles can contribute to the resulting signal (I.E.V. 391-10-55).

*Decay time constant*

The time for a true single-exponential waveform to decay to a value of $1/e$ of the original step height.

*Defined pulse width*

The time elapsed between the first and final crossings of the defined zero level for the maximum rated output pulse amplitude.

*Defined zero*

An arbitrarily chosen voltage level at the amplifier output resolvable from zero by the measuring apparatus.

*Depletion layer (in a semiconductor detector)*

A layer of a semiconductor detector which constitutes its sensitive volume. Most of the energy lost by the particles in this region can contribute to the resulting signal (I.E.V. 391-10-56).

*Differential non-linearity (DNL) (%)*

The maximum percentage departure of slope of the plot of output versus input quantity from the slope of a reference line. When stated as a single number this shall be the maximum value within the specified range.

*Differentiated pulse*

A pulse that is passed through a high-pass network, such as a CR filter.

*Effective feed-back capacitance*

The combined capacitance of the feed-back capacitor and stray capacitances, that determines the conversion gain of a charge sensitive preamplifier.

*Effective test capacitance*

The combined capacitance of the test capacitor and stray capacitances that determines the sensitivity of the test input of the charge-sensitive preamplifier.

*Energy resolution (FWHM) (of a semiconductor radiation detector)*

The detector's contribution (including detector leakage current noise), expressed in units of energy, to the FWHM of a pulse-height distribution corresponding to an energy spectrum.

*Energy resolution (per cent) (of a semiconductor radiation detector)*

One hundred times the energy resolution divided by the energy for which the resolution is specified.

*Equivalent noise charge (ENC)*

The noise contribution of a charge sensitive preamplifier referred to its input, expressed as the r.m.s. value of the noise charge.

*Equivalent noise referred to the input*

The value of noise at the input that would produce the same value of noise at the output as does the actual noise source.

*Full width at half maximum (FWHM)*

In a distribution curve comprising a single peak, the distance between the abscissa of two points on the curve whose ordinates are half of the maximum ordinate of the peak.

*Note.* — If the curve considered comprises several peaks, a full width at half maximum exists for each peak (based on I.E.V. 391-15-08).

*Full width at tenth maximum (FWTM)*

Same as full width at half maximum except that measurement is made at one-tenth the maximum ordinate rather than at one-half.

*FWHM* (see *full width at half maximum*)

*FWTM* (see *full width at tenth maximum*)

*Gain recovery time* (see *amplifier gain recovery time*)

*Geometry, detector*

The physical configuration of a solid-state detector.

*Inactive region (of a semiconductor radiation detector)*

A region of a detector in which charge created by ionizing radiation does not contribute significantly to the signal charge.

*Integral non-linearity (INL)* (%)

The departure from the linear response expressed as a percentage of the maximum rated output pulse amplitude.

*Integrated pulse*

A pulse that is passed through a low-pass network, such as a single RC network or a cascaded RC network.

*Integrating preamplifier*

A pulse preamplifier in which individual pulses are intentionally integrated by passive or active circuits.

*Intrinsic semiconductor (I-type)*

An effectively pure semiconductor in which, under conditions of thermal equilibrium, the charge carrier densities of each sign are nearly equal (I.E.V. 391-05-02).

*Note.* — This term is incorrectly used to designate by extension compensated semiconductors.

*Inversion layer*

For a given type of semiconductor, a surface layer of the opposite type (I.E.V. 391-10-57).

*Junction*

A transition layer between semiconductor regions of different electrical properties, or between a semiconductor and a superficial layer of different type.

This layer is characterized by a potential barrier impeding the charge carriers to move from one region to the other (I.E.V. 391-10-42).

*Leakage current*

The total detector current flowing at the operating bias in the absence of radiation (I.E.V. 391-10-14).

*Lithium drifted semiconductor detector*

A compensated semiconductor detector in which the compensated region is obtained by causing lithium ions to move through a P-type crystal under an applied electric field in such a way as to compensate the charge of the bound impurities (I.E.V. 391-09-45).

*Load impedance (of a semiconductor radiation detector)*

The impedance shunting the detector, and across which the detector output voltage signal is developed.

*Load resistance (of a semiconductor radiation detector)*

The resistive component of the load impedance.

*Monoenergetic source (ionizing radiation)*

A radiation source emitting ionizing radiation of essentially a single energy.

*Noise linewidth*

The contribution of noise to the FWHM of a spectral peak.

*Noninjecting contact (of a semiconductor radiation detector)*

A contact at which the carrier density in the adjacent semiconductor material is not changed from its equilibrium value.

*Ohmic contact (of a semiconductor radiation detector)*

A purely resistive contact, i.e. one that has a linear voltage-current characteristic throughout its entire operating range.

*Peaking time ($t_p$)*

The time elapsed between (1) the first crossing of the defined zero level and (2) the departure of the pulse from peak amplitude, for a pulse whose peak amplitude is equal to the maximum rated amplifier signal output.

*p-i-n detector*

A detector consisting of an intrinsic or nearly intrinsic region between a p and an n region.

*Pole-zero cancellation*

A pulse shaping method, usually by means of a differentiator, eliminating undershoots of long duration.

*Pole-zero cancellation range*

The range of input pulse trailing edge time constants that can be eliminated by the pole zero cancellation network.

*Preamplifier conversion gain*

The output pulse amplitude of the signal expressed in volts divided by its input charge expressed in coulombs. The input signal can also be expressed in kiloelectron volts for a given detector material.

*Pulse fall time*

The interval between the instants at which the instantaneous value of the trailing edge of the pulse reaches specified upper and lower limits, namely, 90% and 10% of the pulse amplitude unless otherwise stated.

*Note.* — In the case of a step function applied to an amplifier that has simple CR - RC shaping, i.e. one high-pass and one low-pass RC filter of equal time constants, the fall time is given by $t_f$ = 3.36 CR.

*Pulse height discriminator*
*Amplitude discriminator*

A discriminator designed to provide an output signal for each input signal the amplitude of which exceeds a predetermined threshold value (I.E.V. 391-11-15).

*Pulse rise time*

The interval between the instants at which the instantaneous value of the leading edge of the pulse reaches specified lower and upper limits, namely, 10% and 90% of the pulse amplitude unless otherwise specified.

*Note.* — In the case of a step function applied to an RC low-pass filter, the rise time is given by $t_{ri}$ = 2.2 RC. In the case of a step function applied to an amplifier that has a simple RC - CR shaping, i.e. one high-pass and one low-pass RC filter of equal time constants, the rise time is given by $t_{ri}$ = 0.57 R.

*RC — CR shaping* (see *CR — RC shaping*)

*Recovery time* (see *amplifier gain recovery time*)

*Resolution, energy* (see *energy resolution*)

*Semiconductor, compensated* (see *compensated semiconductor*)

*Semiconductor radiation detector*

An ionization detector using a semiconductor medium in which an electric field is provided for the collection at the electrodes of the excess charge carriers produced by ionizing radiation (I.E.V. 391-08-13).

*Shaping time constants*

The time constants of the bandwidth defining CR differentiators and RC integrators used in pulse amplifiers.

*Space-charge generation (in a semiconductor radiation detector)*

The thermal generation of free charge carriers in the space-charge region.

*Space-charge region (of a semiconductor radiation detector)*

A region in which the net charge density is significantly different from zero. (See also depletion layer.)

*Spectral line*

A sharply peaked portion of the spectrum that represents a specific feature of the incident radiation, usually the full energy of a mono-energetic radiation.

*Spectrum (of an ionizing radiation)*

Distribution of the values of a specific radiation quantity usually associated with energy, for example emission rate as a function of energy of emitted particles (I.E.V. 391-15-07).

*Straggling, energy*

The random fluctuations in energy loss whereby those particles having the same initial energy lose different amounts of energy when traversing a given thickness of matter. (This process leads to the broadening of spectral lines.)

*Surface barrier semiconductor detector*

A semiconductor detector in which the potential barrier due to the junction results from a superficial inversion layer (I.E.V. 391-09-42).

*Totally depleted semiconductor detector*

A semiconductor detector in which the thickness of the depletion layer is essentially equal to the thickness of the semiconductor material (I.E.V. 391-09-49).

*Transmission detector*

A totally depleted detector whose thickness, including its entrance and exit windows, is sufficiently small to permit charged particles to pass completely through the detector.

*Zero crossover time (of a pulse)*

Crossover time for which the designated level is zero.

*Zero crossover walk (of a pulse)*

A crossover walk for the zero crossover time.